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Adaptive behavior, choice of residential location and localization of labor markets

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Kiel Working Papers

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**Adaptive Behavior, Choice of Residential Location
and Localization of Labor Markets**

by Andreas Kopp



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1 Introduction

There is an extensive literature on why and how localized labor markets may lead to a general concentration of economic activities in geographic space (Fujita/ Thisse 1995). The question how a localization of labor markets comes about has been much less studied and has only recently found increased interest (CEPR). The most prominent of these recent efforts is Krugman's model on labor market pooling (Krugman 1991) referring to Marshall's argument that an industrial center allows a pooled market for workers with specialized skills, such a pooled market benefiting both workers and firms. Assuming that there are firm specific demand or productivity shocks and increasing returns on the firm level the pooled labor market protects firms from labor shortages in good times and workers from being unemployed when the current employer is suffering from negative shocks.

In this paper we look at the localization of labor market localization from a different perspective. It is based on a model of labor turnover that does not rely on product market shocks. Rather, there is uncertainty about the value of individual employment relationships. This uncertainty does not refer to labor

heterogeneity or agency problems but to an unknown productivity of workers who are ex ante identical (or unknown nonpecuniary characteristics of a job). This allows for modeling labor turnover which not only explains separation decisions on the part of the employer but also quit decisions by the employees.

The more employment opportunities exist in the immediate neighborhood of the residential location of a worker the less likely it is that the worker has to bear the costs of a residential relocation when quitting or losing a job. The more workers with desired skills live near the location of a firm the easier it is to fill a vacancy after a separation due to a negative work history.

The employer and the worker agree to make the wage dependent on the observed history of productivities. As the hiring of another worker or to find another employment is associated with transaction costs neither the employer nor the worker can commit to a wage offer or a wage demand, respectively. Therefore, wages have to be decided upon by bargaining (Diamond 1971, McMillan/Rothschild 1994). Taking account of the conceptual (e.g. Fudenberg/Levine forthcoming, Binmore et al. 1996) as well as empirical criticism of non-cooperative bargaining theory (e.g.

Spiegel/Currie/Sonnenschein/Sen 1994) based on the results of experiments, an evolutionary bargaining model is adopted (Young 1993b).

The labor turnover has been previously modeled in the search theoretic models of Jovanovic (1979a, 1979b), Wilde (1979), Viscusi (1979), Johnson (1978) and Mortensen (1986). In these models a job is an "inspection good": Either the true distribution of labor productivities is unknown and the workers get paid according to the expected average productivity, given the observed history of her/his performance, or they learn about non-pecuniary characteristics of the job which might make them switch to another employment. They all focus on the modeling of quit decisions; the employers pay the average product and are therefore indifferent between having a worker with a low or high performance. Separation decisions of employers and workers are studied in Lippman/McCall (1981) and McCall/McCall (1985). The consequences of the cost of turnover for wage determination are not taken into account.

The externality arising from the clustering of workers and employers in the context of job uncertainty has not been studied before. A similar argument has been made for goods markets where the clustering of suppliers creates a

demand externality using standard search theoretic modeling techniques (Wolinsky 1983).

In the next section we discuss how the employers and workers solve the bargaining problem on how to divide the surplus created by a match without knowing the preferences of their bargaining partners or the probability distributions thereof. In section three we present the turnover model assuming that the value of a match is uncertain and that information over its probability distribution is only acquired in the course of the tenure. Section four discusses how the costs of switching an employment relation and the costs of residential relocations influence the separation decisions. This allows to determine the agglomerative force of a cluster of employers and the conditions for a single cluster equilibrium.

2 Wage and profit determination

As set out in the introduction a job is considered to be an experience good. There is no ex ante information on the specific value of a employment relationship. Employers have no information on the valuation of the job by the worker and vice versa. Nor do they have (common) knowledge of the distribution of true productivities of comparable jobs. Given that switching a

job and employing a different worker is costly they cannot commit to a certain wage offer or wage demand. Due to the lack of ex ante information on the types of employers and workers a labor contract cannot be derived from first principles as in cooperative bargaining solutions (Nash 1953, Raiffa 1953) or as the subgame perfect equilibrium of a game in which the players alternate in making offers to one another (Stahl 1972, Rubinstein 1982 and Binmore et al. 1992). To find an agreement on how to divide the surplus created by a job they have to rely on information that is obtained by looking at similar arrangements and appeal to what is usual in similar situations.

To model what employers and workers may consider as "usual" and how this helps them to coordinate we rely on the evolutionary learning models of Kandori et al. (1993), Samuelson (1994) and Young (1993 a,b). Learning does not occur at the individual level out of a bilateral interaction as it is assumed that after a separation of an employment relation the worker does not return to the same employer. It is assumed that each individual has limited information on how the benefits of similar matches have been divided in the past. Coordination arises if the employers and workers refer, initially by chance, to the same precedents. As this establishes a set of common precedents the

individuals begin to expect that similar coordination problems will be solved in the same way in the future. If there is only little variability in agreements due to differences in the agents' behavior and beliefs the process will lead to one division rule that will be observed almost all of the time.

Employers and workers are considered as two finite, nonempty classes of individuals A and B. In each period an agent can only meet one member of the other class to decide on a labor contract specifying a division rule. In an ongoing employment wage payments depend on the actual performance of the worker according to this division rule.

The share demanded by the worker is denoted by y , the share of the employer by x . Only a finite number of divisions is considered. D denotes the set of feasible (positive) demands whose precision is measured by 10^{-p} with p being a positive integer. Employers and workers are randomly matched.

Matched employers and workers then play a Nash demand game: Members of A demand a fraction $x \in D$ and a member of B a fraction $y \in D$ of the surplus of the match which will be determined by a periodic assessment of the performance of the worker. The demands are satisfied if $x + y \leq 1$. If $x + y > 1$ both get nothing and have to wait to be matched again.

The demands (x_t, y_t) form a precedent. The whole set of precedents with t elements is denoted by

$$\bar{s}(x, y) = \{(x_1, y_1), (x_2, y_2), \dots, (x_t, y_t)\}$$

Some of the precedents become outdated or irrelevant such that only the last m records survive.

$$s(x, y) = \{(x_{t-m+1}, y_{t-m+1}), (x_{t-m+2}, y_{t-m+2}), \dots, (x_t, y_t)\}$$

Let an employer α and a worker β be chosen as the match $t+1$. Having neither information or beliefs about the utility function of the other side nor on the distribution of utility functions over the whole population they decide on their demands by relying on a subset of the above precedents that they happen to get to know. The employer draws a random sample of size k_E and the worker a random sample of the size k_W from these m records. k_j ($j = E, W$) measures the degree to which the individuals are informed. Each agent then chooses a best reply to her/his observed frequency distribution of demands. The employer α forms the cumulative frequency distribution $F(y)$ on the demands made by the workers in his sample:

$$\forall y \in D \quad F(y) = h/k_\alpha \text{ iff the sample contains exactly } h \text{ demands of } y_j \leq y.$$

The employer is assumed to have a v. Neumann Morgenstern utility function $u_i(x)$ which is concave, strictly increasing in the employer's own share and defined for all $x \in [0,1]$. The utility functions are normalized such that the utility of a disagreement is equal to zero, i.e. $u_i(0) = 0$. If α demands x and β a share of y the employer gets x if $y \leq (1-x)$ and zero otherwise. That is, the expected utility, given the sample information, is

$$u_i(x)F(1-x) + u_i(0)[1-F(1-x)] = u_i(x)F(1-x). \quad (1)$$

In game $t+1$ that demand x is chosen which maximizes the expected utility:

$$x_{t+1} = \operatorname{argmax} u_i(x)F(1-x). \quad (2)$$

If the solution is not unique each of the solutions is chosen with positive probability.

In the same way the worker draws a sample of size k_w at random from the last m plays and chooses an optimal response to the demands of the employers.

The response rules just described determine a stationary Markov chain. The state space consists of sequences s of length m whose elements are the surviving precedents of the demand game. $p_i(x|s)$ denotes the conditional

probability of the demand x iff x is the best reply by α to a sample of size k_E drawn from s .

Every pair of an employer with a vacancy and a worker seeking employment have a positive probability $\pi(\alpha, \beta)$ of being matched¹ which depends on the switching behavior as will be explained in section 4.

Given a state $s = \{(x_{t-m+1}, y_{t-m+1}), (x_{t-m+2}, y_{t-m+2}), \dots, (x_t, y_t)\}$ another state s' is said to be a successor of s if it has the form $s' = \{(x_{t-m+2}, y_{t-m+2}), \dots, (x_t, y_t), (x_{t+1}, y_{t+1})\}$. Depending on the precision of the demands, the memory m , the relative sample sizes of the agents k_j/m ($j = E, W$) as well as the best reply distributions $p_E(x | s)$ and $p_W(y | s)$, the transition probability that the process will move from state s to a successor s' with the completion of the Nash demand game $t+1$ is

$$P_{ss'} = \sum_{\alpha \in A} \sum_{\beta \in B} \pi(\alpha, \beta) p_E(x_{t+1} | s) p_W(y_{t+1} | s) \quad (3)$$

If a fixed division $(x, 1-x)$ were repeated m times, the Markov process defined by (3) reaches an absorbing state. After arrival in such a state every employer

¹ In other cases than the one discussed here the matching probability may depend on the geographic distance between the locations of the agents, the matching probability decreasing with communication or transportation costs. Here we assume that the information on job opportunities is not dependent on the distance between the residential location of a job seeker and the location of a potential employer

observes that workers demand $(1-x)$ and the unique optimal reply is to demand $x > 0$. Similarly the workers find that in all the demand games they sampled the employers claimed a share of x of the surplus generated by the labor relation. Hence, their best reply is $(1-x) > 0$. Consequently, after agreement $t+1$ the process is in the same state as after game t . As has been shown by Young (1993a,b, 1995 Theorem 1) the process indeed converges with probability one to such a division rule if the relative sample size in each class is sufficiently small, or more precisely smaller than or equal to half of the surviving records. However, process (3) does not tell to which division rule the process will finally converge. It has as many absorbing communication classes as there are pure strategy Nash equilibria, i. e. division rules.

The evolutionary process defined in (3) is based on the assumption that agents always choose best replies given their information. For the sake of realism (and to avoid that the process settles down on local rather than global optima) it is assumed that agents experiment by choosing sometimes other than best reply strategies or make mistakes. Let ϵ be the absolute probability with which agents in general experiment and λ_E and λ_W the relative probabilities with which particular agents experiment. $q_E(x|s)$ be the conditional probability

that α chooses the reply x given that α is experimenting and that the current state is s . $q_\beta(y | s)$ is analogously defined for the workers. q_w and q_W are assumed to have full support to ensure that in any given situation all demands can be made with positive probability. The additional assumptions on experimentation lead to revised transition probabilities of moving from state s to s' at time $t+1$:

$$\begin{aligned}
 P_{ss'}^{\varepsilon} = & \sum_{\alpha \in \Lambda} \sum_{\beta \in B} \pi(\alpha, \beta) \left[(1 - \varepsilon \lambda_{\alpha}) (1 - \varepsilon \lambda_{\beta}) p_{\alpha}(x|s) p_{\beta}(y|s) + \right. \\
 & + \varepsilon \lambda_{\alpha} (1 - \varepsilon \lambda_{\beta}) q_{\alpha}(x|s) p_{\beta}(y|s) + \varepsilon \lambda_{\beta} (1 - \varepsilon \lambda_{\alpha}) p_{\alpha}(x|s) q_{\beta}(y|s) + \\
 & \left. + \varepsilon^2 \lambda_{\alpha} \lambda_{\beta} q_{\alpha}(x|s) q_{\beta}(y|s) \right]
 \end{aligned} \quad (4)$$

$P_{ss'}^{\varepsilon} = 0$ if s' is not a successor of s . The process P^0 is identical to the unperturbed process (3). If ε is positive the perturbed process P^{ε} is irreducible (all states communicate with each other) because of the assumption that the experimental distributions q_E, q_W have full support. This implies that P^{ε} has a unique stationary distribution μ^{ε} . As the process is also aperiodic (positive recurrent) it is strongly ergodic: For every $s \in S$, μ_s^{ε} is the relative frequency with which state s will be observed in the first t periods as $t \rightarrow \infty$. Hence, if the agents occasionally experiment the process has no absorbing states. It has been shown (Young 1993a), however, that $\lim_{\varepsilon \rightarrow 0} \mu^{\varepsilon}(h) = \mu^0(h)$ exists, where μ^0 is a

stationary distribution of the unperturbed process P^0 . That is, if ε is very small, the unique stationary distribution of P^ε is close to some *particular* stationary distribution of P^0 . These conditions define the emergence of a stable division rule: If $\lim_{\varepsilon \rightarrow 0} \mu^\varepsilon(h) = \mu^0(h) > 0$ exists the division rule implied is called stochastically stable, if $\lim_{\varepsilon \rightarrow 0} \mu^\varepsilon(h) = 1$, it is strongly stable. A strongly stochastically stable division rule will be observed almost all of the time if ε is small.

The particular strongly stochastically stable division rule can be computed by using graph theoretic techniques. This also allows to show that a strongly stable division rule exists for all parameter values (cf. Appendix).

3 Learning about the value of a job and the expected tenure

Both parties consider the output as random. In accordance with the sampling of precedents of the Nash demand game as a device to coordinate on a labor contract they periodically assess the value of the match. The worker's realized output provides a noisy signal for the average output for the future tenure. This information is used to set the current wage, is a predictor of future incomes and is the basis of possible separation decisions. The wage is equal to the expected

match value times the share the employer and the worker have agreed upon on the basis of the evolutionary bargaining process described in the previous section. The conditional predictor of the future productivity becomes more and more precise with the duration of the employment relation as a consequence of the law of large numbers. The workers can leave the current employer at any time and switch to another of the ex ante identical jobs, depending on the general labor market situation and the efforts the workers and employers undertake to find a new job or to fill a vacancy. The value of quitting is the expected present value of future earnings on the first day of any new job. Once separated the worker will not return. Therefore, the probability that the worker will leave even if the true average match specific productivity is higher than in any other job is positive as a consequence of the sampling variation.

It is assumed that the productivities of the worker can take one of N values z_1, z_2, \dots, z_N . Similar to the sampling that the agreement on the division rule was based on, the underlying distribution is multinomial with unknown values $\pi_1, \pi_2, \dots, \pi_N$, $\pi_i \geq 0$, $\sum_1 \pi_i = 1$. The prior distribution on $\pi_1, \pi_2, \dots, \pi_N$ is Dirichlet² with parameters $\alpha_1, \alpha_2, \dots, \alpha_N$. The expected prior distribution is multinomial

² The Dirichlet specification is chosen for ease of exposition. A more general learning rule which would lead to the same qualitative results has been presented by Bikchandani and Sharma (1996).

with parameters $\alpha_i/\sum\alpha_i$. As the family of Dirichlet distributions is a conjugate family for observations which have a multinomial distribution (DeGroot 1970, ch. 9) the posterior distribution of $\pi_1, \pi_2, \dots, \pi_N$ after observing productivity z_i is Dirichlet with parameters $\alpha_1, \alpha_2, \dots, \alpha_i+1, \dots, \alpha_N$. The underlying expected posterior distribution is multinomial with updated parameters $(\alpha_1/\sum_j\alpha_j+1, \dots, \alpha_i+1/\sum_j\alpha_j+1, \dots, \alpha_N/\sum_j\alpha_j+1)$. In the limit the true underlying distribution would be known with certainty.

In the context described, stopping corresponds to quitting the job. Let $t \geq 0$ be the worker's tenure on the job. $\{z_t\}$ represents the stochastic process generating the time path of realized productivities as long as the worker stays with the employer.

At time t the employer and the worker have observed the productivities z_1, z_2, \dots, z_t . A strategy σ is a decision rule which tells the searcher whether to continue the job after observing this sequence of values or to quit the job and search for another one. It does so for all possible sequences. To each possible sequence of values the decision rule assigns a peculiar stopping time which is a random variable whose probability distribution will depend on the searcher's beliefs and on the strategy σ . Alternatively, the strategy can be presented in

terms of a reservation value. If a productivity lower than the reservation value is observed there will be a separation decision and the initialization of another employment relationship.

Proposition 1: The solution to the search problem of finding the true value of the match has the properties that there is

- (i) a decreasing value of continuing the job,*
- (ii) an optimal quitting rule which is myopic and has the reservation value property,*
- (iii) a finite expected time of continuing the job,*
- (iv) an increasing sequence of reservation values.*

Proof: At the beginning of a work history the employer and the worker agree on a wage that refers to public information of similar jobs. In making a quit or continuation decision this is translated into an accounting value z_0 by multiplying it with the inverse of the shares agreed upon. It is assumed that the searcher expects a match value for the first period after an assessment has been made that is higher than the threshold value that would make him quit all of the time, given that the first wage is chosen by reference to public information like

the wage statistics. It is first shown that the value of continuing the job is a decreasing function of the length of the tenure. Let us define

$$\pi_j = \frac{\alpha_j}{\sum_{j=1}^n \alpha_j} \text{ as the initial belief of the searcher of the probability with which a}$$

productivity z_i will be observed. Let $1 / \sum_{j=1}^N \alpha_j$ be denoted by ρ . To exclude that

the searcher anticipates job switches all of the time we have to assume that the value of the productivity z_0 is not higher than what the worker expects to be the first observation in the series of productivity assessments, i.e.

$$z_0 < \delta \sum_{i=1}^N \pi_i z_i. \text{ Starting from any period } t \text{ the maximal gain the worker can}$$

expect from continuing the job is the one that results when the highest productivity z_N is observed all of the time. The undiscounted expected payoff after T periods is then

$$Z_T^* = \sum_{t=1}^T \left\{ \frac{1}{1 + t\rho} \sum_{j=1}^N \pi_j z_j + \frac{t\rho}{1 + t\rho} z_N \right\}. \quad (5)$$

The undiscounted total expected payoff after $T+1$ periods is

$$Z_{T+1}^* = \sum_{t=1}^{T+1} \left\{ \frac{1}{1+t\rho} \sum_{j=1}^N \pi_j z_j + \frac{t\rho}{1+t\rho} z_N \right\}. \quad (6)$$

As the gain from continuing one more period in T we obtain

$$\begin{aligned} Z_{T+1}^* - Z_T^* &= \frac{1}{1+(T+1)\rho} \sum_{j=1}^N \pi_j z_j + \frac{(T+1)\rho}{1+(T+1)\rho} z_N \\ &< \frac{1}{1+\rho} \sum_{j=1}^N \pi_j z_j + \frac{\rho}{1+\rho} z_N \end{aligned} \quad (7)$$

which is clearly smaller than the gain of observing one more z_N after period T . If the undiscounted value of continuing the job is decreasing over time, this holds a fortiori for the discounted value. From this follows that the longer the tenure lasts the more and more attractive get the alternatives. A consequence of this fact is that with wage levels (determined by the history of productivity observations) close to the initial wage level of a new job, quitting becomes more and more attractive as the expected value of getting productivity values at the upper end of the spectrum becomes more and more unlikely given the reduced uncertainty about the true productivity distribution of a certain match. Therefore, if the expected payoff of continuing the job in the next period is lower than what the searcher would expect when quitting today, and if this difference is smaller than the difference between the observed productivity

value z_t and z_0 , she/he should leave the job today. Let us assume that the next productivity value will not be lower than the productivity value of today and that this value occurs with probability $p_t = \sum_{z_1 \leq z_t} \pi_1$ and with complementary probability the maximal value z_N will be observed. The quitting criterion would then be

$$z_t - z_0 < \delta \{ p_t z_1 + (1 - p_t) z_N - p_t z_t - (1 - p_t) z_N \}, \text{ or}$$

$$p_t \geq \frac{z_t - z_0 + \delta p_t (z_N - z_t)}{\delta (z_N - z_t)} \quad (8)$$

The right hand side is the higher the higher the current expected productivity is above what is implied by the initial wage level and the smaller the difference between the highest productivity and the current expected productivity. The greater the right hand side the less probable it is that an improvement in the expected productivity level will occur. Denoting the right hand side by r , an upper bound for the length of the tenure is then given by

$$T^* = (rs - s_1)/(1-r), \quad (9)$$

where s_t denotes the sum of the initial Dirichlet distribution over the values lower or equal to what is expected for the first period. s denotes the total of the parameters of the Dirichlet distribution.

Let $f_t(z)$ be the undiscounted expected net gain of switching to another job in period $t+1$

$$f_t(z) = \sum_{i=1}^N \pi_i z_i - \sum_{i=1}^N \frac{1 + h_i \rho}{1 + (t+1)\rho} \pi_i z_i \quad (10)$$

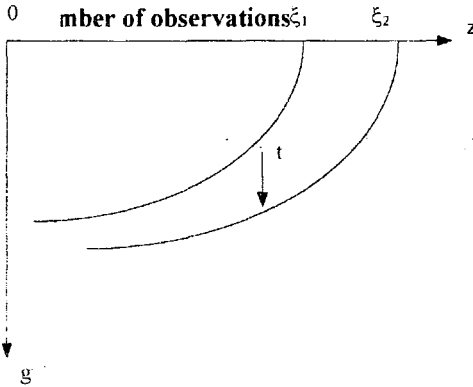
The h_i denote the frequencies with which the z_i have been observed and hence sum up to $t+1$.

Since in period T^* the continuation of the job stops for sure the searcher should stop in period T^*-1 if $z_t^* - z_0 < \delta f_{T-1}(z)$. We then define a function

$$g(z) = (s+t)[z_t - z_0 - \delta f_t(z)] \quad (11)$$

For all t , $g(z) \leq 0$ for $z = z_0$, and therefore the set $Q_t = \{z \in \{z_1, z_2, \dots, z_N\} | g(z) \leq 0\}$ is non-empty. Let ξ_t denote the maximum of all $z \in Q_t$. g is decreasing in t , because of the multiplier $(s+t)$ and an increasing f_t , and increasing in z . Therefore, ξ_t are increasing with t .

Figure 1: Reservation values as a function of observed productivities and



That is, the reservation values of observed productivities which cause a separation in case they are undercut by the observed sample values increase over time. The reason for the increasing reservation values is the "preference for risk" of the searchers: The existence of the quit option allows the worker to avoid low value realizations. As a consequence they prefer dispersion in the future values because only the higher realizations are relevant. As the expected value of continuing a job declines because of the decrease of the expected variance of observed productivity values the reservation value is a strictly increasing function of the sample size.

4 The interdependence of quit and residential location decisions

In order to model the localization of the labor market we have to add structure to the above model of wage determination and separation behavior.

As a first step the transaction costs of switching the job are detailed. Instead of assuming that the worker who quits a job can immediately find an alternative employment for sure we suppose that the probability of encountering an employment opportunity depends on the worker's search intensity $s_w \in [0,1]$ and the intensity s_E with which the employers seek to fill their vacancies as well as on the ratio of vacancies to job seekers. If the worker does nothing to find a new job the probability that she or he will be contacted is equal to

$s_w^0 = \frac{N_E}{N_w} s_E$, where N_E denotes the number of vacancies and N_w the number

of unemployed. The total probability of finding an employment opportunity is then

$$s_w^1 = s_w + \frac{N_E}{N_w} s_E.$$

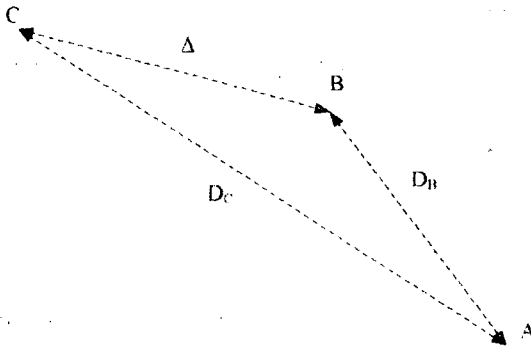
The higher the intensity of search the higher will be the cost of search. We define a cost function $c = c(s_w)$ with $c' > 0$ and $c'' > 0$. The convexity of the search cost function ensures that an optimal s_w^* and s_j^* exists as the quitting value becomes a strictly concave function of the search intensity.

The evolution of the number of job vacancies and job seekers is the result of the equilibrium turnover resulting from the above model of separations and on the initial number of agents of each type. To concentrate on the issues of localization it is assumed that the flows of vacancies and job seekers are constant over time. This implies that the endogenous rate of the initialization of labor relations is equal to the number of separations.

In addition to these search costs a worker is assumed to incur costs of a residential relocation if she or he cannot find an employment in the immediate neighborhood. An immediate neighborhood is defined as a point in geographic space. While the search costs of finding another job are assumed to be independent of the geographical distance between the residential location of the worker and the location of the prospective employers the costs of relocation are assumed to be linearly dependent on the distance between the initial and the new workplace.

To determine the localization effect of these conditions we assume the following geographic structure: A worker searches for a job from a location where he cannot find (further) employment opportunities. This location is called A. There is one location with just one potential employer, B, and a third location C with $(N_E - 1)$ relevant job vacancies. The distance between his initial residential location and point B is denoted by D_B , the distance to C by D_C and the distance between B and C by Δ

Fig. 2: Residential location and locations of employment opportunities



A localization effect would be assessed when there is a configuration of relocation costs and expected careers such that a job seeker would reject an offer should that offer happen to from the single firm location.

Proposition 2: For a number of potential employers N_E greater than some N_E^ there exists a distance $\Delta(N_E^*) > 0$ such that if $\Delta < \Delta(N_E^*)$ every worker with a difference in mobility costs smaller than $t(D_C - D_B)$ prefers to wait for a job offer in the cluster.*

The decision whether to accept or-reject a job offer in the B depends on whether the worker expects to quit during his remaining work life, how the level of income that she/he expects on that first job in B compares to the income in the cluster C and on how large the difference in migration costs is. Given the above assumptions the criterion for quitting a current job changes to

$$z_t - \left(s_w^* + s_E \frac{N_E}{N_W} \right) (z_0 - c(s_w^*) - tD_j) < \left(s_w^* + s_0 \frac{N_E}{N_W} \right) \left(\delta \sum_{i=1}^N \pi_i z_i \right) - \delta z_{t-1} \quad (12)$$

with $j = B, C$ and z_{t+1} denoting the expected value, given the history of observed productivities up to period t .

The above variable r derived under optimistic assumptions on the career in equation (8) then reads

$$r = \frac{z_t - \left(s_w^* + s_E \frac{N_E}{N_W} \right) (z_0 - c(s_w^*) - tDj) + \delta(z_N - z_{t+1})}{\delta(z_N - z_0)} \quad (13)$$

As can be seen from equation (9) the duration of the tenure is a positive function of r . Therefore the expected length of the tenure depends positively on the

- the number of vacancies,
- cost of switching the job,
- the distance of prospective migration and the cost of migration per distance unit,

and negatively on

- the search intensities, and
- the number of job seekers.

Therefore, the expected time of continuing the job in location B is greater than the one expected for location C. From equation (9) using equation (13) we can calculate upper bounds for the length of these time periods, T_B and T_C . The difference in net discounted income between accepting a job in B or waiting for a job offer in C consists of t

- the cost of unemployment as the job seeker cannot expect to immediately getting a job in C after turning down an offer in B,
- the lower income in B after T_c due to his lower reservation value because of the migration costs,
- the difference in the costs of residential relocations,
- the possible unemployment after quitting the first job in C. should he again get a job offer in B.

The expected waiting time of getting a job in the cluster after having turned down a job offer in B is equal to the smallest integer k such that

$$k \left(s_w^* + \frac{N_E - 1}{N_w} s_E^* \right) \geq 1.$$

An upper bound for the cost of unemployment Z_{ij} is then calculated, assuming as before that the expected match values are not declining and if higher values than the initial expected value are observed they are equal to the highest value:

$$Z_{ij} = z_0 + \sum_{t=1}^{k-1} \left\{ \frac{\delta^t}{1 + t\rho} \sum_{i=1}^n \pi_i z_i + \frac{\delta^t t\rho}{1 + t\rho} z_N \right\} \quad (14)$$

From the end of the prospective occupation in location C, T_C to the end of the job in location B the job seeker expects the discounted maximum total income

$$Z_{T_C-T_B}^B = \sum_{t=T_C+1}^{T_B} \left\{ \frac{\delta^t}{1+t\rho} \sum_{i=1}^N \pi_i z_i + \frac{\delta^t(t-T_C)\rho}{1+t\rho} z_N \right\} \quad (15)$$

For the same time period the expected income in location C, the job seeker has instead just started a new job and expects earning

$$Z_{T_C-T_B}^C = \sum_{t=1}^{T_B-T_C} \left\{ \frac{\delta^{T_C+t}}{1+t\rho} \sum_{i=1}^N \pi_i z_i + \frac{\delta^{T_C+t}t\rho}{1+t\rho} z_N \right\} \quad (16)$$

Moving directly to the cluster the job seeker has to incur higher mobility costs proportional to the difference between D_C and D_B . As she/he will always refuse to move to location B he gains $\delta^{T_B}\Delta$ as there is no relocation between B and C.

The total benefit of rejecting a job offer at the single firm location is then

$$M = Z_{T_B-T_C}^C - Z_{T_B-T_C}^B - Z_U - t(D_C - D_B) + \delta^{T_B}t\Delta. \quad (17)$$

The greater Δ , the longer will be the continuation on the job in location B and the longer will be the period $T_C - T_B$. The longer that period the higher will be the difference between the first two terms on the right hand side of (17). The higher the number of job opportunities in the cluster the lower is Z_U and the

higher is M . Hence there is a decreasing schedule $\Delta(N_{FE})$ for which $M = 0$. The higher the difference between the distances between location B and C the lower is the critical distance $\Delta(N_{FE}^*)$, corresponding to indifference between accepting a job in B or in C. From this follows directly Proposition 3.

Proposition 3: If N_{FE}^ is such that $M \geq 0$ even for the case $D_C = \Delta + D_B$ all job seekers within a distance of D_C around C will reject offers in B. If the radius D_C includes all of the geographical area considered there is a single cluster equilibrium.*

5 Employers' separation decisions and firm location

Employers decide on the separation from a worker in the same way the worker decides on a quit decision. The observation of low productivities imply low profits for the employer. The decreasing variance of the expected productivities implies an increasing reservation value for continuing the employment relationship on the part of the employer. Who first makes a separation decision depends on the initial beliefs of the parties on the distribution of productivity values.

In the above geographical situation, given that workers have reason to reject job offers in a single firm location, an employer could not profitably locate a firm outside the cluster. A change of a given geographical situation could result from differences in the growth of clusters which could lead to abrupt changes of the agglomerative force of a cluster.

6 Conclusions

The paper investigates the condition of localized labor markets when there is uncertainty about the quality of labor market matches. As the separation of an employment relation is costly the terms of a labor contract have to be determined by bargaining. As there is no common knowledge of the employers' and workers' utility functions (or their distribution over the whole population) nor repetition of transactions between identical partners, this coordination problem has to be resolved by an evolutionary bargaining process based on reference to observable characteristics of other, similar agreements.

More and more precise information on the probability distribution of the match values of ex ante identical jobs is obtained from periodic assessments of the productivity of a worker. Due to a decreasing variance of expected match

values, incentives to switch to another job or to employ another worker are increasing over time.

It is shown that the residential location decisions of workers under these conditions imply a stable localized labor market in the sense that firms are unable to meet labor supply outside a cluster within a certain distance around the cluster that depends on the number of employment opportunities and costs of residential relocation. The conditions for a single cluster equilibrium are identified.

Appendix: Computation of the minimum resistance between m -records

If $\mathbf{s} = \{(x_{t-m+1}, y_{t-m+1}), (x_{t-m+2}, y_{t-m+2}), \dots, (x_t, y_t)\}$ is some state and

$\mathbf{s}' = \{(x_{t-m+2}, y_{t-m+2}), (x_{t-m+3}, y_{t-m+3}), \dots, (x_{t+1}, y_{t+1})\}$ is a successor of \mathbf{s} , an

employer has made a mistake in the transition $\mathbf{s} \rightarrow \mathbf{s}'$ if x_{t+1} is not a best reply for any of the employers to any sample of the size k_E drawn from \mathbf{s} . Similarly, y_{t+1} is a mistake if, for every worker, it is not a best reply to any sample of size k_W drawn from \mathbf{s} . The minimum number of mistakes required to move from one state \mathbf{s} to a successor \mathbf{s}' in a one-period transition is called the resistance $r(\mathbf{s}, \mathbf{s}')$. It can take on the values 0, 1 or 2. The values for the resistances are computed by solving a shortest path problem on a directed graph (where the edges are weighted with the total number of mistakes leading to a one-step transition)

Let $\mathbf{x}^1, \mathbf{x}^2, \dots, \mathbf{x}^n$ be the absorbing states of P^0 . Due to the above convergence result there is no transition from any \mathbf{x}^i to \mathbf{x}^j ($i \neq j$) with zero resistance. There must be however at least one path between these state with positive resistance since the perturbed process P^ϵ is irreducible. Each of the absorbing states contains identical records which establish a fixed division rule. We now define a graph G which is composed of the absorbing states \mathbf{x}^i ($i = 1, 2, \dots, n$) as vertices and a directed graph from every vertex to every other. The graph is turned into a network by weighting the edges by the resistances $r(\mathbf{x}, \mathbf{x}')$ of moving from one fixed division rule to another.

A state is then stochastically stable if $\mathbf{s} = \mathbf{x}$ contains only identical elements and has minimum stochastic potential among all \mathbf{x} (Young 1993a, Lemma 1 and Lemma 2).

To compute the minimum resistance one has to construct a directed graph in which every state is a vertex, containing an edge from s to s' if and only if s' is a successor of s . $r(s,s')$ is the weight attached to the edges of the directed graph.

Let G be another graph containing a vertex for each s with identical elements, denoted by \mathbf{x} , corresponding to the absorbing classes of P^0 , and a directed edge from very vertex to every other. To each of the edges we assign the weight $r(\mathbf{x},\mathbf{x}')$. For each fixed vertex k ($1 \leq k \leq n$), define a k -tree to be a spanning tree in G such that all paths lead to k . The resistance of a k -tree T is the sum of the resistances of its edges: $r(T) = \sum_{\mathbf{x},\mathbf{x}' \in T} r(\mathbf{x},\mathbf{x}')$.

The stochastic potential of an \mathbf{x} defined as above is the minimum resistance among all k -trees:

$$\gamma(\mathbf{x}) = \min_{T \in \mathcal{T}_{\mathbf{x}}} \sum_{\mathbf{x},\mathbf{x}' \in T} r(\mathbf{x},\mathbf{x}') \quad (1')$$

The sequence of stationary distributions μ^ε converges to a stationary distribution μ^0 of P^0 as $\varepsilon \rightarrow 0$. Moreover, s is stochastically stable ($\mu_s^0 > 0$) if and only if $s = \mathbf{x}$, i.e. contains only identical records, and $\gamma(\mathbf{x})$ has minimum stochastic potential among all such vectors of identical records. Such an \mathbf{x} implies a stable division rule that resolves the coordination problem of an employer and a worker initiating a labor relation.

In the sequel it will be shown how such a stable division rule is determined by the size of the samples of the employers and the workers as well as by the composition of these groups. To do so we first have to find out how to compute

the minimum resistance between any two states characterized by m identical records. Secondly it is explained how a division $(x, 1-x)$ is stochastically stable if and only if x maximizes the minimum resistance between any pair of m vectors of identical records.

Let a be a rational fraction ($0 < a < 1$) of the last m records that is sampled by the employers. We start out from the assumption that all employers have identical utility functions $u(x)$, u being a concave function defined for all $x \in [0, 1]$. The workers are assumed to sample fraction b of the last m records and to have a concave utility function $v(1-x)$ defined for all $x \in [0, 1]$. m is chosen such that ma and mb are integer. Without loss of generality we can assume that $a \geq b$. $k = ma$ be the absolute number of records sampled by the employers. Under the condition that both of the types of agents don't sample more than half of the surviving records there exists at least one and at most two generically stable divisions.

The set of the feasible demands is fixed by the choice of the precision $\delta = 10^{-p}$, p being a positive integer, $D^0 = \{x \in D: \delta \leq x \leq 1-\delta\}$. For every real number r let $[r]$ denote the least integer greater than or equal to r .

Minimum resistance between m -vectors of identical records

We first have to find out how we can determine the minimum resistance between any two states (vectors of m identical records). For the transition from one m record of identical records to another one the employers, the workers or both have to (mistakenly) deviate from the division rule $(x, 1-x)$ that has become conventional. That is, they make demands that do not correspond to the best reply rule in equation (1). A mistake could consist of demanding more than is

conventional or by demanding less. Suppose the process is at the convention $x \in D^0$. Let ψ be the path of minimum resistance from x to a state s that is in some other basin. ψ must then go through some other state s such that the employers' best reply is different from x or the workers' best reply is different from $(1-x)$. Let s be the first of such states. If an employer's best reply to a sample σ is $x' \neq x$ then by choice of s some of the workers must have made a mistake by demanding a share different from $(1-x)$. Let $i \leq k$ be the number of mistakes contained in the sample σ of the employer. We construct another sample σ' of the employer where we replace all the mistakes that have been made by the workers in σ by the demand $(1-x')$. As the employer's best reply to σ was x' this holds a fortiori for the sample σ' .

We now construct an alternative path ψ' from x to the x' -basin in which the total number of mistakes is i . If ψ had been a transition path to x' this must then also hold for the path ψ' : Beginning at the m -vector x let a succession of workers mistakenly demand $1-x'$ in a row. For any employer who is matched in the next period will sample the most recent k records with positive probability this sample σ'' consists of i elements $(1-x')$ and $(k-i)$ elements of $(1-x)$. The relative frequency of mistakes is the same as in the sample σ' . If all employers have the same utility function, and x' has been a best reply in the first place to σ' , it follows that x' is also the best reply by any other employer to the sample σ'' .

With positive probability the landlords will sample σ'' for k periods in succession and reply with x' each time. The workers who sample the most

recent records will then observe a sample that contains only the demands x' . As there is a positive probability that a succession of k workers will sample from this run, and consequently ask for $1-x'$ for k rounds in a row. It follows that the process converges with positive probability to the m vector x' with no further mistakes.

To compute the minimum resistance for a transition from x to every x' we have to consider for every $x' \neq x$ the least number of initial mistakes $(1-x')$ which would imply best responses of x' by the employers, and the least number of initial mistakes x' by the employers that would cause a worker to reply with $1-x'$. The smaller of these two number would give the minimum resistance.

Choosing an arbitrary $x' \neq x$, we have to distinguish two cases, a transition to a new division rule which implies a smaller share of the employers or a transition rule associated with a higher share of the employers.

Transition to a smaller share of the employers

First the employers can make the bad mistake of demanding $x' < x$ i times in a row which causes some workers to switch to the demand $(1-x')$ instead of $(1-x)$. i can be smaller than the entire sample size of the workers mb . It follows from equations (1) and (2) that if the workers observe i demands x' and $(mb-i)$ demands x they switch to the demand $(1-x')$ if $(i/mb)v(1-x') \geq v(1-x)$, or

$$i \geq mb \frac{v(1-x)}{v(1-x')} \quad (2')$$

The minimum value of i occurs if the employers would make the worst mistake and demand the smallest possible $x' = \delta$:

$$i = mb \frac{v(1-x)}{v(1-\delta)} \quad (3')$$

A second possibility is that the workers by mistake demand a higher share than what is a best reply to their samples when starting from x . Suppose that a succession of $j \leq k = ma$ workers erroneously demand $(1-x')$. An employer who samples the j mistakes switches to the best reply x' if $u(x') \geq (1-j/k)u(x)$, or

$$j \geq k \left(1 - \frac{u(x')}{u(x)} \right) \quad (4')$$

Over all feasible $x' < x$, the *minimum* such j occurs when $x' = x-\delta$. Consequently, the minimum resistance is equal to

$$j = ma \left(1 - \frac{u(x-\delta)}{u(x)} \right) \quad (5')$$

Transition to a larger share of the employers

Similarly the employers could make demands which are higher than the best replies to the samples containing k times the element $(1-x)$. If the employers make i mistaken demands of x' , then some workers will switch to a lower $(1-x')$ provided that

$$i \geq mb \left(1 - \frac{v(1-x')}{v(1-x)} \right) \quad (6')$$

The minimum number of mistakes to leave x is associated with the smallest deviation from the conventional demand, when $x' = x+\delta$:

$$i = mb \left(1 - \frac{v(1-x-\delta)}{v(1-x)} \right) \quad (7')$$

If the workers make j mistaken demands of $(1-x')$ then some employers switch provided that

$$j \geq ma \frac{u(x)}{u(x')} \quad (8')$$

The minimum number of mistakes is required if the mistaken demands $1-x'$ are minimal, i.e. $1-x' = \delta$. We then have

$$j = ma \frac{u(x)}{u(1-\delta')} \quad (9')$$

Let $[r]$ denote the smallest integer greater than or equal to r . Combining (7) to (10) it then follows that the least number of mistakes to exit from x is $[mr_\delta(x)]$, where

$$r_\delta(x) = \min \begin{cases} a \left(1 - \frac{u(x-\delta)}{u(x)} \right) \\ b \left(1 - \frac{v(1-x-\delta)}{v(1-x)} \right) \\ b \frac{v(1-x)}{v(1-\delta)} \\ a \frac{u(x)}{u(1-\delta)} \end{cases} \quad (10')$$

The fourth term can be omitted as it is at least as large as the second term for all $x \in D^0$. (Young 1993b, p. 160). A peculiar division is generically stable if and only if x maximizes the function $r_\delta(x)$ on D^0 .

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